Ocean Variability Effects on Underwater Acoustic Communications

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LONG-TERM GOALS

This proposed research seeks to identify, explain, and ultimately predict the factors that significantly alter the operational effectiveness of underwater acoustic communications through experimental work and theoretical analysis. The long-term goal is to develop reliable, high rate transceivers customized for coherent underwater acoustic communications.

OBJECTIVES

The research objective is to investigate the relationship between environmental fluctuations and the performance of coherent underwater acoustic communications at high frequencies (8-50 kHz) through experimental research and data analysis. High rate communication methods are to be developed based on the understanding of acoustic propagation physics in dynamic shallow water environments.

APPROACH

Significant data rate increases can be achieved through the use of multiple-input/multiple-output (MIMO) systems in the underwater channel [1]. Our approach is to develop time reversal MIMO processors [2] for the high frequency underwater channel. The receiver structure is shown in Fig. 1. Time reversal followed by a single channel decision feedback equalizer (DFE), aided by frequent channel updates, is used to compensate for the time-varying inter-symbol interference (ISI). For single source systems, frequent channel updates are needed in time reversal processors to deal with the channel fluctuations within a data packet. Here the time-varying ISI is addressed

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in the MIMO processor through the use of frequent channel updates. The time reversal DFE method was applied to active MIMO time reversal communication [3], where multiple data streams were transmitted and demodulated through a two-way signaling process. Multiuser communication was also demonstrated by passive time reversal followed by a DFE for each data stream [4]. In the frequency band of 3-5 kHz, the channel changed slowly and was considered time-invariant during each transmitted packet [3-4]. In the literature, a number of efforts have also been focused on the development of the MIMO or multi-user receivers based on multichannel DFEs [5], for example [6-7].

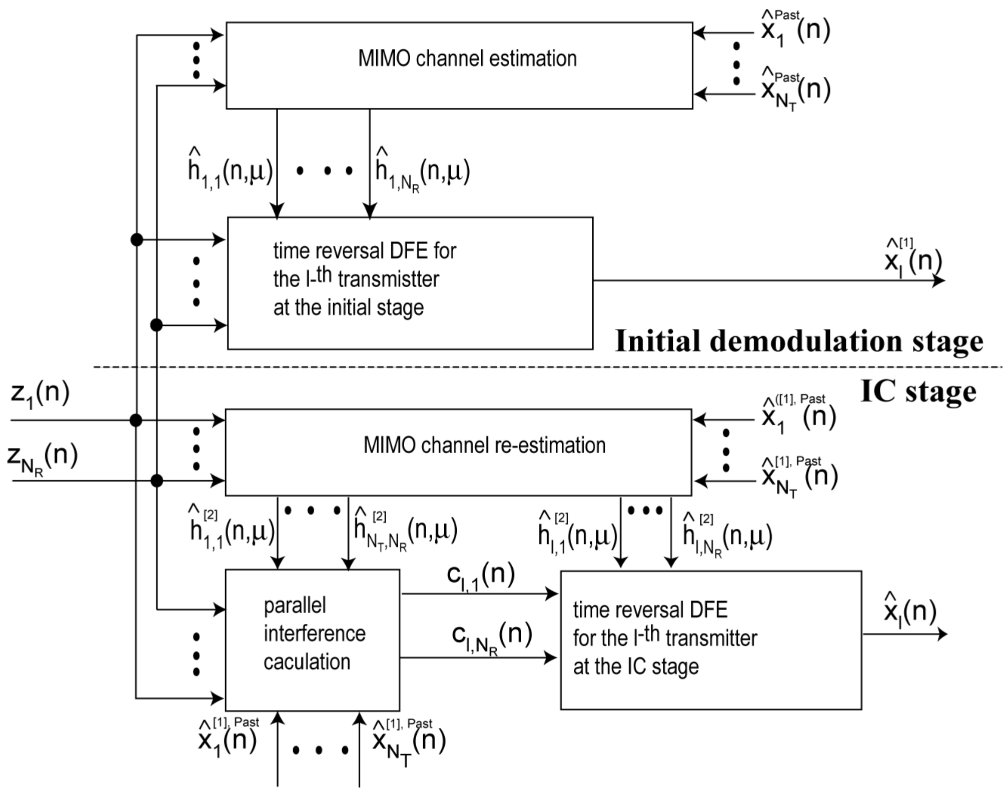

Fig. 1. Time reversal DFE with parallel IC for the l-th data stream. In the two-stage receiver structure, the time reversal DFE is applied twice, first on the received signal to obtain initial demodulation results and second on the interference-removed received signals to obtain the final results.

In addition to the time-varying inter-symbol interference (ISI), co-channel interference (CoI) occurs as a result of multiple data streams sharing the channel at the same time and at the same bandwidth. CoI is addressed in time reversal MIMO processors. For the fast fluctuating channel, the receiver structure based on a parallel interference cancellation (IC) method in Fig.1 preserves the low-complexity of the time reversal processor. Further, iteration of the IC, channel estimation, and time reversal DFE is used. The resultant receiver produces significant performance improvements in the underwater MIMO channel. Although IC methods have been investigated thoroughly for different wireless communication channels, their application in time-varying

multi-path environments such as the underwater channel has been limited. For example, serial IC was incorporated into the iterative decoding structure that was based on the multi-channel DFE for the underwater channel [7]. Serial IC was developed for time reversal MIMO receivers in our previous studies [8]. The CoI in multiuser acoustic communication was suppressed by using constrained Wiener filtering in the underwater environment [9].

WORK COMPLETED

Data analysis of the KAM08 experiment. The Kauai Acoustic communications MURI (KAM08) experiment was conducted west of Kauai, Hawaii, during summer 2008. The MIMO communication performance is demonstrated for an extended period (35 hours) during KAM08. With extended acoustic measurements along with concurrent environmental observation, the objective was to study the MIMO communication performance over the 35 hour period. Environmental impacts on acoustic communication were previously studied for single source systems during the Kauai experiment (KauaiEx) [10] conducted at the same site during summer 2003. The effects of ocean thermocline fluctuations on noncoherent acoustic communication [11] as well as on phase-coherent communication [12] were investigated for a near-seafloor source over a 27 hour period. More recently, the impacts of source and receiver geometry on single source communication were reported over the same period of KAM08 as in this paper [13].

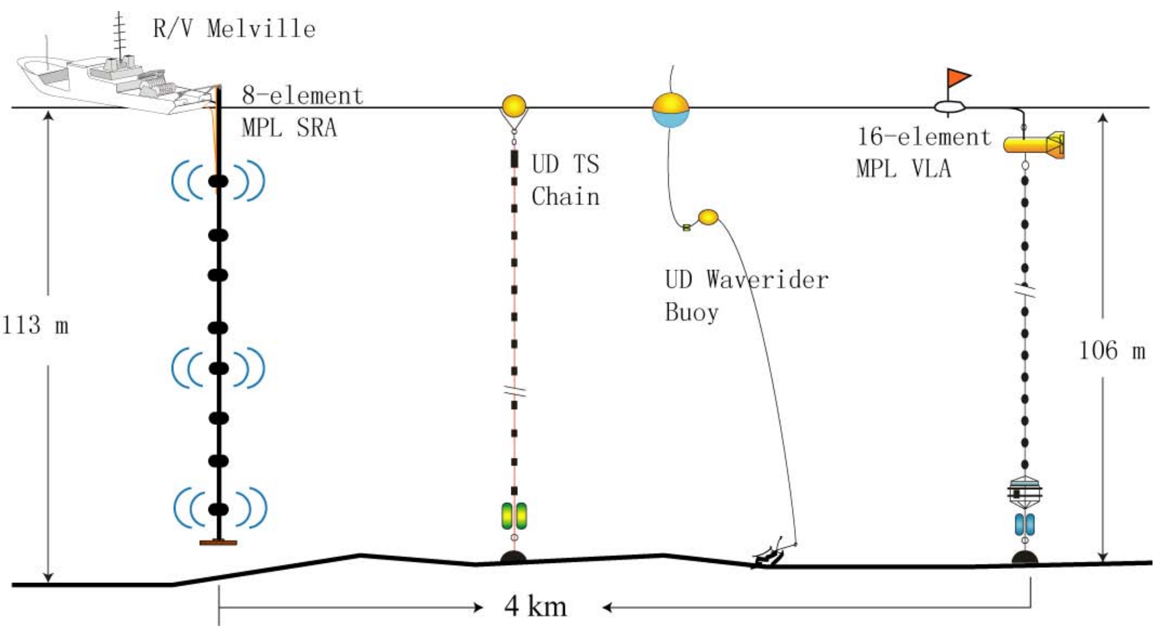

Fig. 2. KAM08 MIMO experimental setting. An 8-element source array was deployed off the stern of R/V Melville and a 16-element vertical line array was moored at a range of 4 km from the source array. The water depth at the source array was about 113 m.

MIMO data from the 35 hour period JD180 (June 28) 05:50:00Z to JD181 (June 29) 16:50:00Z have been analyzed. As shown in Fig. 2, an 8-element source array was deployed off the stern A-frame of the R/V Melville. The element spacing of the source array was 7.5 m, with the top

transducer at a nominal depth of 30 m. The source level was 185 dB re 1 μPa at 1 m. A 1000-lb weight was suspended from the end of the cable to keep the source array vertical during acoustic transmissions. The ship was in dynamic positioning mode to keep the source motion minimal over scales of seconds. As a result, the source drift was less than 10 m. The water depth at the source array was about 113 m.

A 16-element vertical line array (VLA) was moored along the 110 m isobath at a range of 4 km from the source array. The element spacing was 3.75 m, with its 56.25-m aperture covering approximately half the water column. The bottom element was positioned 7.5 m above the sea floor. The sampling frequency of the acoustic data was 50 kHz. The BPSK signals from the bottom four transducers are analyzed. There are four source configurations: 1-transmitter at 82.5 m depth, 2-transmitters at 75 and 82.5 m depths, 3-transmitters 67.5, 75, and 82.5 m depths, and 4-transmitters at 60, 67.5, 75, and 82.5 m depths. The deepest transducer or hydrophone is indexed as the first throughout the paper. These four types of BPSK signals were transmitted every hour from JD180 05:50:00Z to JD181 16:50:00Z. The carrier frequency of the BPSK signal was 16 kHz and the symbol rate was 4 kHz. The square-root raised cosine shaping filter was used with an excess bandwidth of 50%.

RESULTS

Figure 3 shows the performance results for 1-, 2-, 3-, and 4- transducer packets along with the water temperature profiles measured at the receiving array. The periodic training symbols were used to re-train the equalizer and to aid the MIMO channel estimation. Note that except for four (4) of four-transducer packets, acceptable performance are achieved during the experiment, with BERs below 8%.

During the 35 hour period, there were significant changes in the receiver performance for both the single source [Fig. 3(b)] and MIMO [Fig. 3(c)-(e)] transmissions under the changing ocean environment. The source depth and VLA aperture are shown in Fig. 3(a). Note two geotimes: hour 18 (vertical dashed line) when the water column was well-mixed down to 100 m, and hour 25 (vertical solid line) when the water column was highly stratified. The four sources and the VLA were in a well-mixed environment during hour 18. During hour 25 all four transducers were below the thermocline, whereas only the bottom half of the VLA was below the thermocline.

For single source communication, Fig. 3(b) confirms our previous results [12]. At hour 25, the output SNR was about 4.6 dB higher than that from hour 18. This was because the downward refracting environment generated stronger insonification at the VLA during hour 25. Similar results can be observed for MIMO data packets. For the 2-transmitter packets, the output SNRs were 9.0 and 6.9 dB for the transducers at the depths of 82.5 m and 75.0 m during hour 18 while they were 12.7 and 11.6 dB during hour 25, respectively. The performance improvement was 3.7 dB for both data streams. For the 3-transmitter packets, performance improvements caused by the ocean environment were 3.9, 4.0, and 4.4 dB for the three transducers. For the 4-transmitter packets, the performance improvements were 3.3, 4.9, 2.4, and 6.3 dB. Enhanced communication performance was also noted during the first several hours of the experiment, when the ocean was highly stratified (Fig. 3).

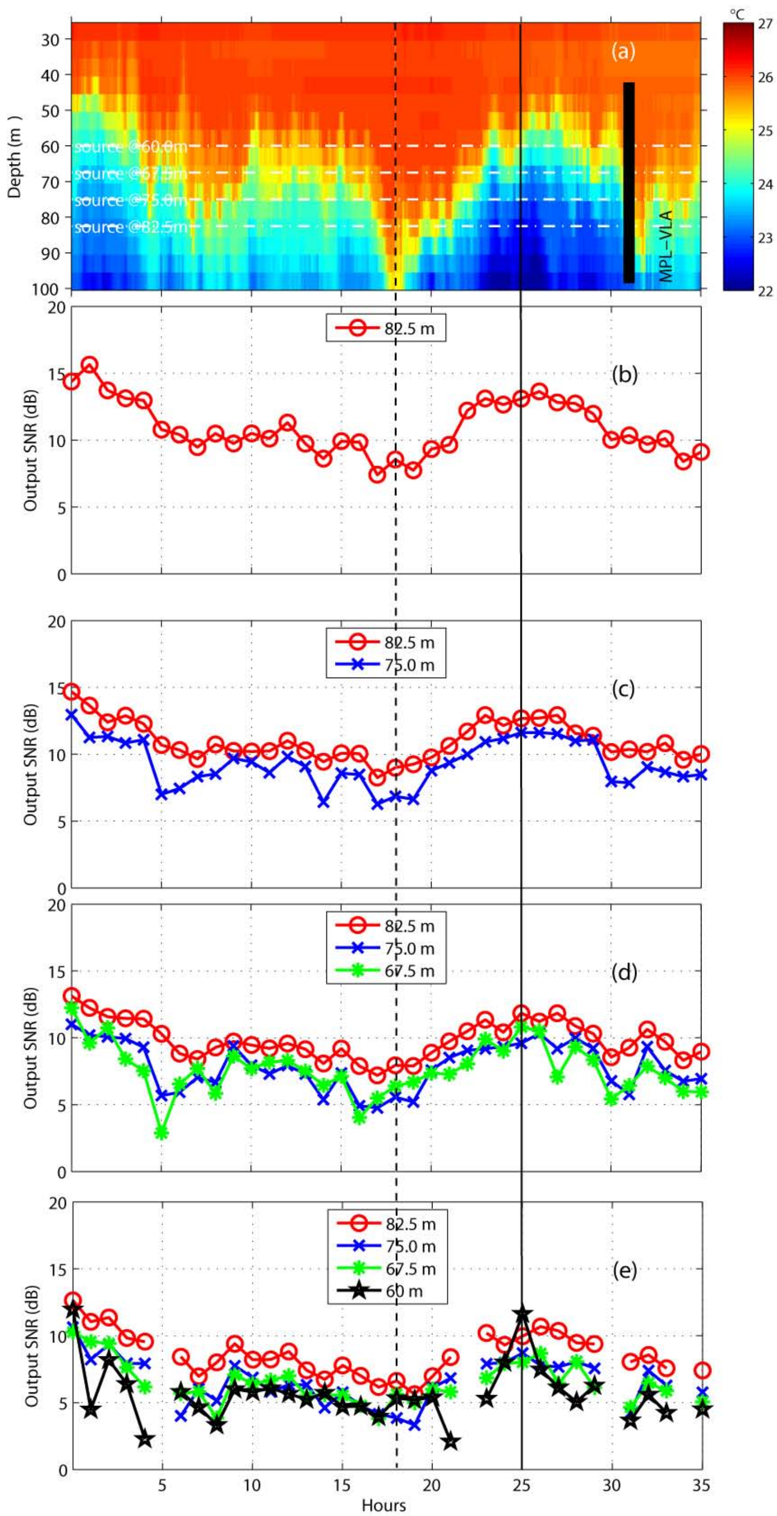

Fig. 3. 35 hour MIMO communication performance during the KAM08 experiment. Along with the temperature profiles measured at the VLA (a), the output SNRs are shown (b) for single source communication; (c) for 2-transducer packets; (d) for 3-transducer packets; and (e) for 4-transducer packets.

IMPACT/APPLICATIONS

The developed receiver is a low-complexity structure for robust, high data rate underwater digital communications at high frequencies. It can drastically improve data rates of underwater acoustic modems. The relationship between ocean environment fluctuations and acoustic modem performance can guide future modeling efforts.

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